Precision measurement of the positive muon lifetime at the RIKEN-RAL muon facility

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Abstract. We performed a precision measurement of the positive muon lifetime at the RIKEN-RAL muon facility. A strong pulsed-muon beam was for the first time used to improve a data accumulation rate of the muon decay events. The most dominant systematic error in the present experiment was a count-loss effect caused by pile-up signals in a high rate data acquisition. To reduce this effect muon decay positrons were observed by using a multi-segmented detectors and residual count-loss events are corrected numerically in the off-line analysis. We obtain a preliminary result of the muon lifetime by this novel method . Further analysis is in progress.

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INTRODUCTION

Precision measurement of the positive muon lifetime (τ_{μ^+}) was performed with a strong pulsed beam at the RIKEN-RAL muon facility. The muon lifetime is directly associated with the Fermi coupling constant (G_F), which is one of the fundamental parameters in the weak sector of the Standard Model (SM). The relationship between G_F and τ_μ was calculated including a two-loop QED radiative correction [1], by which τ_μ can be translated to G_F with an accuracy better than one ppm. At present, the precise measurement of τ_μ can give the most precise value of G_F by using this relation.

The most precise G_F (9 ppm accuracy PDG average [2]) is not obtained by this way. The most accurate value of τ_{μ^+} was determined by the TRIUMF group in 1984 to an accuracy of 27 ppm [3]. Since then, no improvement has been done for more than 20 years.

EXPERIMENT

We have developed a novel method of the muon lifetime experiment at the RIKEN-RAL muon facility [4]. The following two points were taken into account; one is to increase a muon accumulation rate to improve a statistical error. Since the method in the previous experiments was limited by a low event accumulation rate, the strong pulsed beam was used to increase the rate drastically. About 200 muon decays in a double-pulse were measured with a positron detector (solid angle $\sim$ 6 %). Another important issue is to control systematic errors associated with data acquisition in a high event rate. The largest systematic error in this method was a count-loss effect caused by pile-up signals.

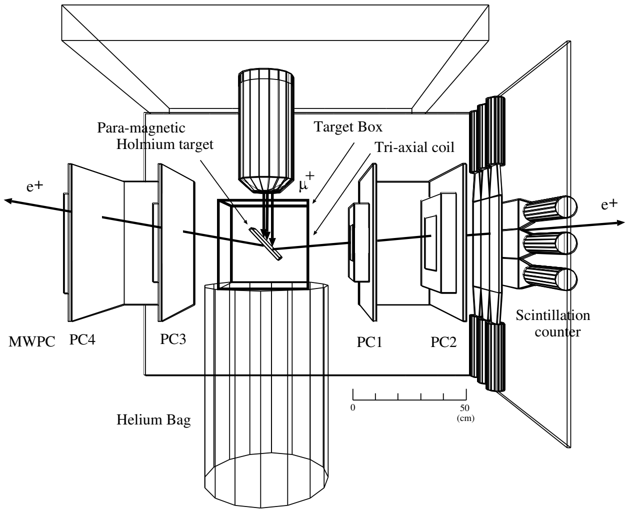

FIGURE 1. Experimental set-up

In order to suppress this effect and other systematic errors, the experiment was designed with the following features:

- A multi-wire proportional chamber (MWPC) was used as a highly segmented detector. In total, 192 segments were achieved if only larger chambers were used. Multi-segmented detector can reduce the event rate for each wire to be about 1.0 counts/spill.
- An accurate clock system combining with a GPS clock was developed.
- A para-magnetic holmium was chosen as a muon stopping target. The polarized muon beam made an anisotropic decay-positron distribution. The holmium depolarized muon spin so rapidly that it could reduce the asymmetry effect on the decay-positron time spectrum.
- In a off-line analysis, the count-loss was numerically corrected on the event-by event basis method.

A detail of the set-up was reported in Reference [5]. In the RIKEN-RAL experiment, a few 10^{10} muon decays have been already accumulated and our first goal is to improve the τ accuracy at a level of 10 ppm.

Figure 1 shows the experimental setup at the RIKEN-RAL muon facility. The surface muon beam was provided at a momentum of 27 MeV/c and at a repetition rate of 50 Hz. All of them are polarized to the anti-parallel direction to the muon momentum. About 10^4 to 10^5 muons per pulse were stopped at a paramagnetic holmium target installed in a target box. The decay positrons were observed with four sets of MWPCs during a time window of 70 μsec. MWPCs were mounted symmetrically on both sides of the target to minimize the spin asymmetry effect.

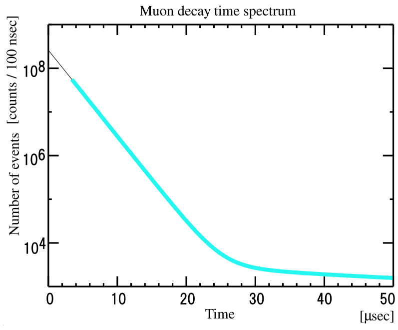

FIGURE 2. Muon decay time spectrum (preliminary). The bold line shows the fitting region in the present analysis.

DATA ANALYSIS

Figure 2 shows a preliminary time spectrum after the count-loss correction. In the off-line analysis, a count-loss correction scheme was developed with a help of Monte Carlo simulation. The count-loss was expressed by power series of e^{-t/τ_μ} and it was corrected for the real data set in a numerical way. After the count-loss correction, the time spectrum was fitted. We chose a fitting function had a exponential muon-decay term (a time constant of τ_μ), a exponential background term (a time constant of τ_{bg}) and a constant background term:

$$f(t) = Ae^{-t/\tau_\mu} + Be^{-t/\tau_{bg}} + C, \tag{1}$$

where A, B, C, τ_μ and τ_{bg} are free parameters. In order to test the goodness of the correction in a high rate region as well as in a low rate region, the start time of the fitting region was changed from the time zero to 10 μsec with a 100 nsec step and a consistency of the lifetime over those regions was carefully examined. In the present analysis, the obtained lifetime values were consistent with each other after the start time of 3.5 μsec region. Near time zero region, some systematic effects which distort the spectrum still remained. This effect will be the source of the most serious systematic error and the other systematic effects are expected to be smaller than this. Setting the start time of the fitting time at 3.5 μsec, the total error (statistical and systematic) was about 50 ppm in the preliminary analysis. We are now investigating systematic error sources to control and evaluate the systematic errors. We are also trying to improve statistics by applying new analysis scheme. We expect that the total error will be reduced by further analysis and the muon lifetime accuracy will be improved from the present analysis precision.

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